pp. 609-614

N64-20016

CODE NONE

Reprinted from JOURNAL OF THE ATMOSPHERIC SCIENCES, Vol. 20, No. 6, November 1963, pp. 609–614
Printed in U. S. A.

Experimental Confirmation from the TIROS VII Meteorological Satellite of the Theoretically Calculated Radiance of the Earth Within the 15-Micron Band of Carbon Dioxide

W. R. BANDEEN, B. J. CONRATH AND R. A. HANEL

Goddard Space Flight Center, Greenbelt, Md.

15 August 1963

One of the five channels of the medium resolution scanning radiometer (Bandeen *et al.*, 1961) on the TIROS VII Meteorological Satellite, launched on 19 June 1963, is sensitive within the 15 micron CO_2 band. This measurement was stimulated by the general interest in the infrared horizon of the Earth and was carried out to test earlier theoretical calculations (Hanel *et al.*, 1963). Preliminary data reduction shows good agreement between experimental results and our calculations. The theoretical radiance values of the Earth and their independence of cloudiness, the predicted seasonal effects, and a small amount of limb brightening have been confirmed.

All of the aforementioned effects are of importance in

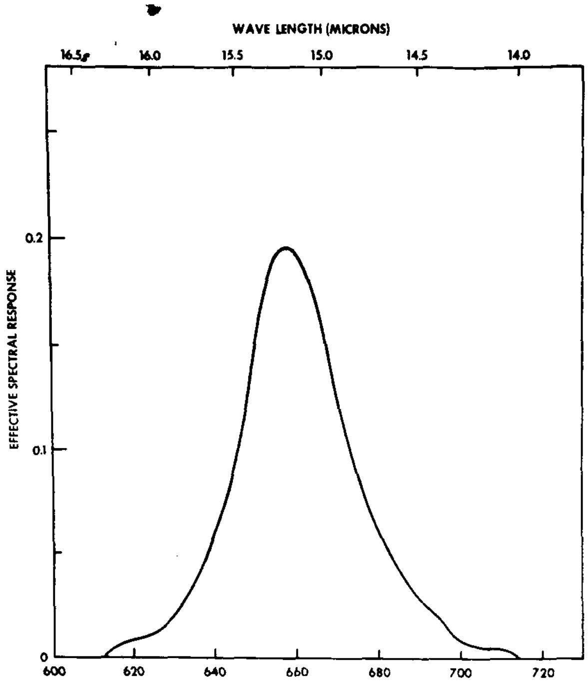

FIG. 1. Effective spectral response of the TIROS VII 15-micron channel.

a consideration of the horizon sensing problem. However, a determination of the detailed structure of the horizon, also important to horizon sensing, cannot be made from the experimental data; a much smaller field of view than the 5 deg of the TIROS radiometer would be necessary to resolve its true shape. Of even greater importance, perhaps, is the geophysical implication of the measurements, comprising a global map of the temperatures in the lower stratosphere.

The spectral response of the instrument is shown in Fig. 1. The absorptivity of the thermistor bolometer and the reflectivities of the chopper and prismatically shaped reflector are taken into account, as well as the transmission characteristics of the interference filter and the KRS-5 lens. The effective aperture of the instrument is 0.5 cm². The peak transmission of the filter is relatively low and the bandwidth narrower than necessary; both factors contribute to the lower signal-to-noise ratio in this channel compared to the other channels. The average generalized absorption coefficient for carbon dioxide within the filter function (log $L \sim 0.25$) is only slightly higher than the average generalized absorption coefficient used in our calculations. Computed and experimental data are therefore not exactly comparable, but the difference is insignificant for most purposes.

Analog traces of signals from all five channels of the TIROS radiometer are shown in Fig. 2. Six individual scans corresponding to six rotations of the satellite can be identified. Between scans, both sides of the radiometer view outer space, which serves as a zero radiation calibration reference. The calibration of the three channels sensitive to infrared radiation is given in terms of the temperature, T_{BB} (deg K), of a black body filling the field of view of the radiometer. The effective radiant emittance of the target, $\bar{W}$ (watts per meter²), is calculated by integrating the Planck function at the temperature T_{BB} over the effective spectral response of the channel. The calibration of the two channels sensitive to solar radiation is given in terms of the effective radiant emittance from a diffuse reflector illuminated by the sun. Actually, the 5 deg field of view more nearly measures the effective specific intensity or radiance, $\bar{N}$ (watts per meter² per sterad) in the direction of the satellite. Of course, for an ideally diffuse source, the relationship $\bar{W}=\pi\bar{N}$ holds. The low temperatures in the 8- to 12-micron and 8- to 30-micron channels, visible in the middle of each swath, and simultaneous maxima in the channels sensitive to reflected solar radiation, identify clearly an extensive area of high cloudiness. The 15-micron channel shows no correlation with the other channels; the radiance of the earth in this wavelength region is virtually independent of the state of cloudiness. The fine structure on top of the 15 micron trace is mostly detector and amplifier noise and not real, as can be seen from the appearance of the space reference level.

A case of limb-darkening in the 8- to 12-micron and 8- to 30-micron regions, and limb-brightening in the 15-micron band can be observed over an apparently cloud-free area in Fig. 3. Again most of the fine structure must be attributed to noise.

In Fig. 4, $\bar{W}$ values averaged over swaths from horizon to horizon, without regard to viewing angle, are plotted versus subsatellite latitude. The values were taken about every fortieth swath (approximately every $4\frac{1}{2}$ min) which is deemed to be sufficient since radiance values change only slowly over the period of one orbit. Data were plotted for the wall and floor sides of the radiometer for six orbits (1, 4, 5, 14, 18 and 19). The lowest values appear over the high latitudes in the southern hemisphere (antarctic winter) and the maxima occur at high latitudes in the northern hemisphere (arctic summer). Data obtained over mid-latitudes and tropical zones exhibit minor variations, but temperatures are generally between 225K and 240K.

The physical meaning of these blackbody temperatures can be judged from Fig. 5, which shows the relative contributions of atmospheric layers to the radiance measured by the radiometer; curves are shown for the 14- to 16-micron region, and the actual filter function of TIROS VII for a zenith angle of zero. Atmospheric emission in the vicinity of 15 to 25 km contributes most, and the regions below 10 and above 40 km contribute only very little, to the radiance at normal incidence. When regions near the horizon are within the field of view of the sensor, the center of mass of the emission function shifts to higher (and warmer) altitudes; hence, limb-brightening occurs. The temperatures shown in

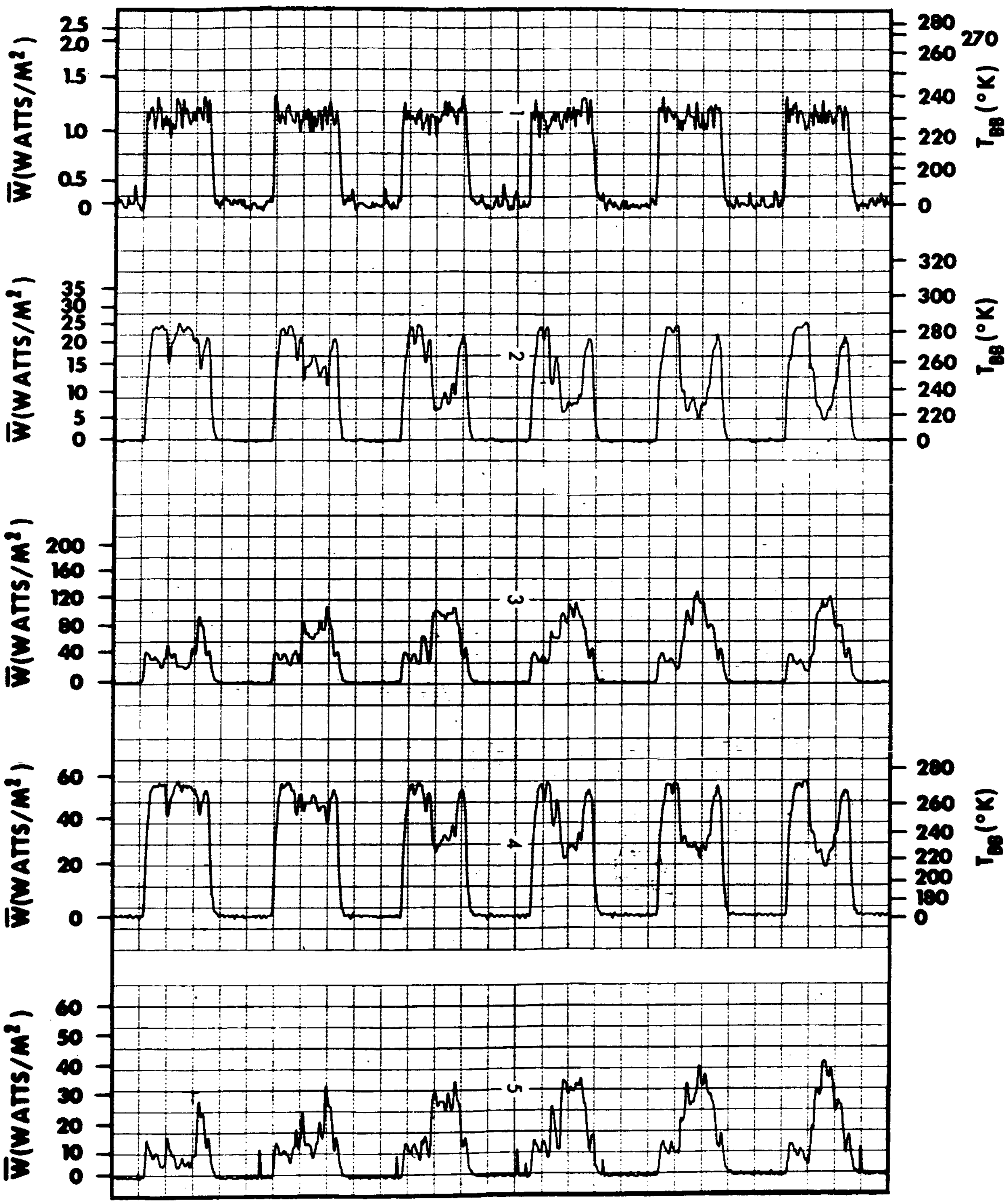

FIG. 2. Oscillogram showing six scans off the east coast of Africa by the TIROS VII radiometer. The approximate wave length intervals of the channels from top to bottom are: 14.8–15.5 μ, 8–12 μ, 0.2–5 μ, 8–30 μ, and 0.55–0.75 μ. The effects of high clouds are illustrated.

Fig. 4 can therefore be interpreted to be average atmospheric temperatures weighted over varying altitudes, depending upon atmospheric structure and sensor viewing angle. The weighting function for the particular case of vertical incidence over a standard atmosphere is indicated by the 14.8–15.5 μ curve in Fig. 5. In theory, using the method proposed by King (1956), the actual temperature profile can be derived from these data. However, the low signal-to-noise ratio will make this a rather difficult task for TIROS VII.

In summary, data from the 15-micron channel of the TIROS VII scanning radiometer have confirmed ex-

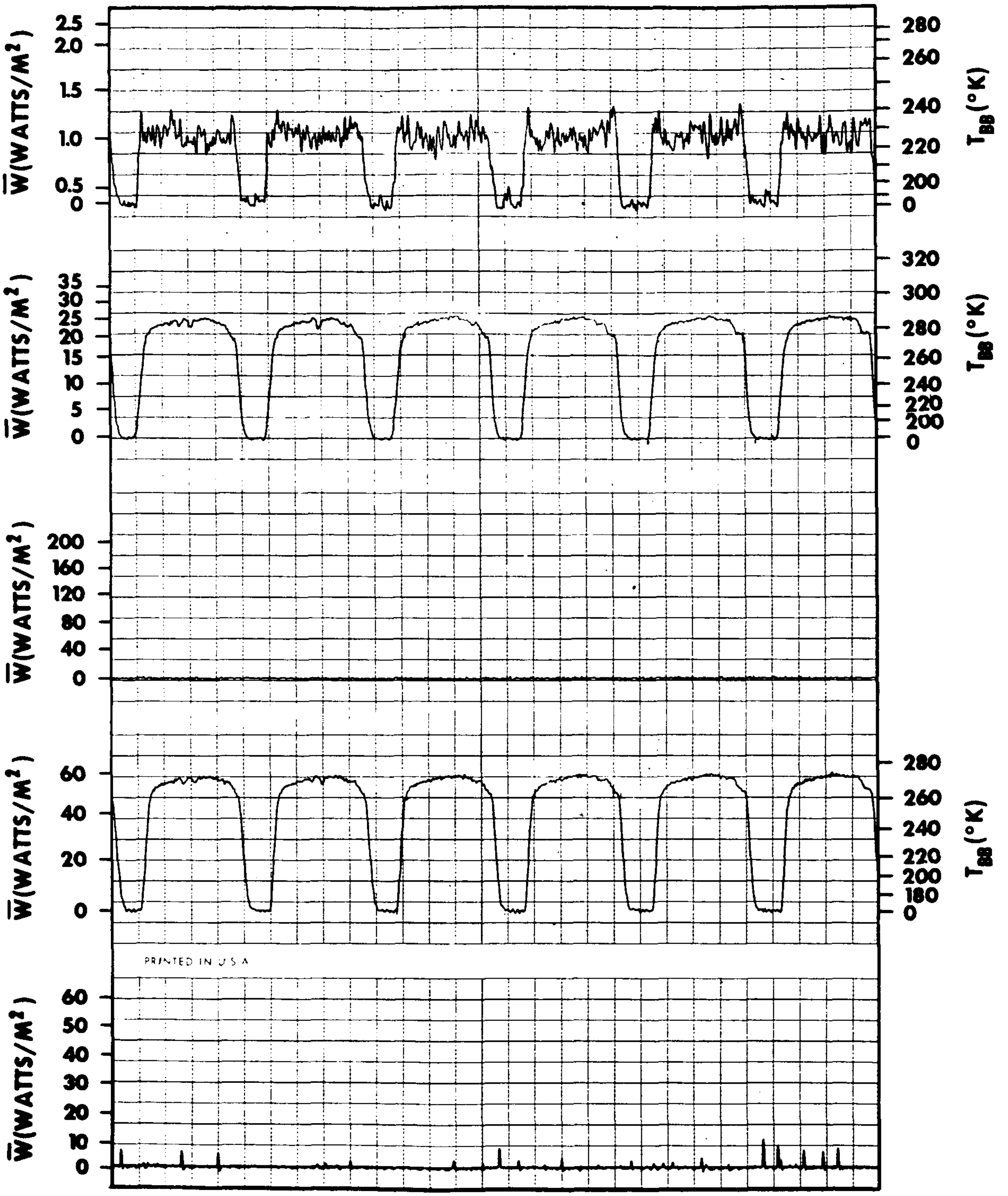

FIG. 3. Oscillogram showing six scans over the tropical Pacific Ocean at night. The channels are in the same order as in Fig. 2. Limb effects are illustrated.

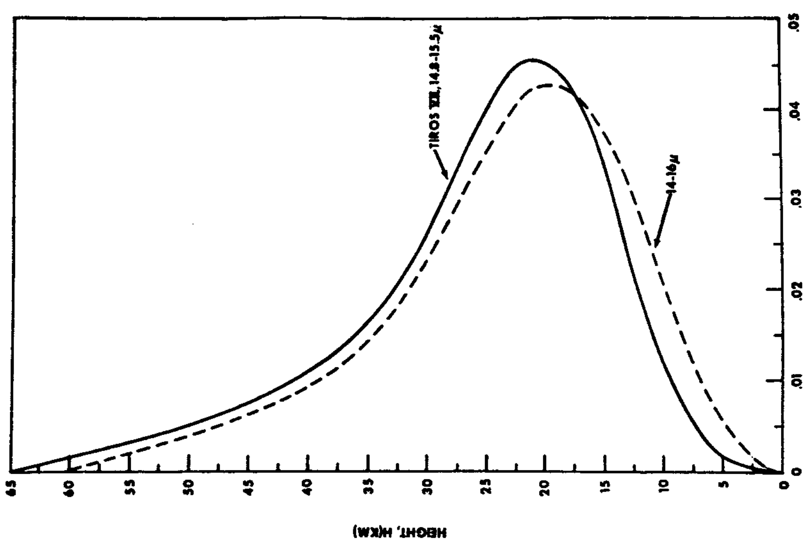

FIG. 5. The relative contributions of layers of the ARDC 1959 model atmosphere to the vertical outgoing radiance in the interval 14–16 μ and within the effective spectral response of the TIROS VII 15 μ channel. Since the transmission, τ, from the surface to the top of the atmosphere within these wavelength intervals is essentially zero, the area bounded by each curve is unity.

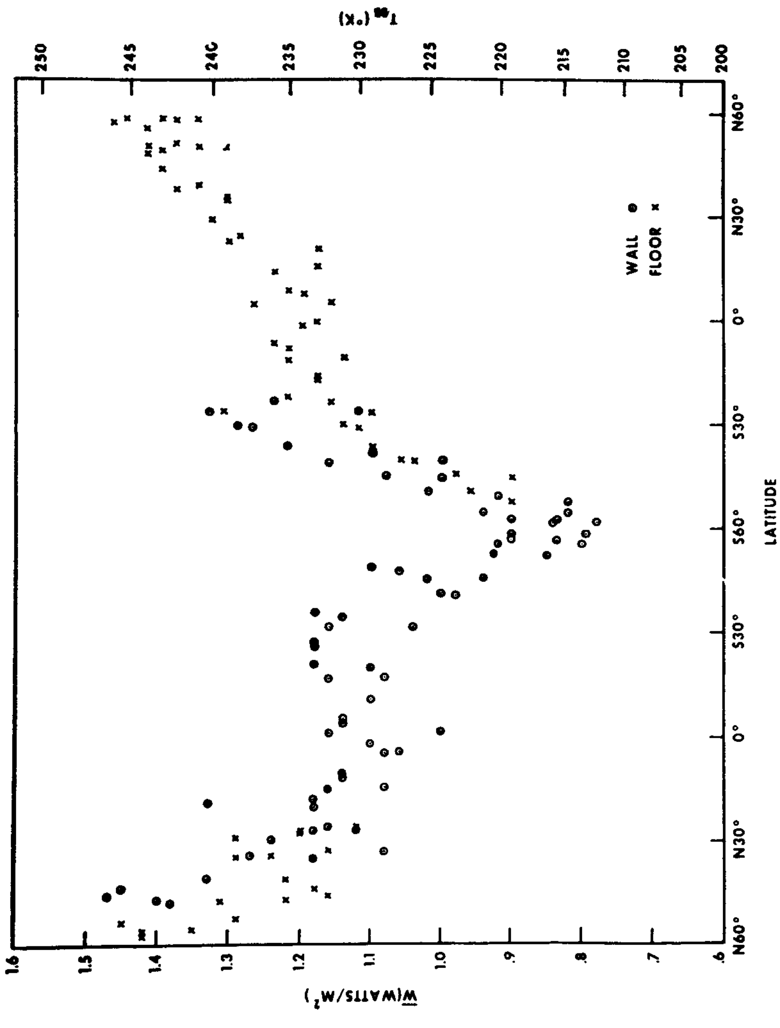

FIG. 4. Average radiation levels throughout six orbits vs. the subsatellite latitude. Measurements made through the satellite baseplate (floor) and side (wall) are separately identified.

pectations. The minimum and maximum blackbody temperatures observed agree well with theoretically predicted values. Lowest temperatures occur in the Antarctic winter and highest in the Arctic summer. A small but definite amount of limb-brightening is observed. Except for seasonal effects, which presumably can be predicted, the radiance within the 15-micron band is very uniform and virtually independent of cloudiness, a fact most desirable for the purpose of horizon sensing. The observation of the temperature of the lower stratosphere on a global basis may become a valuable tool for the study of the general circulation of the atmosphere. One possible application would be the detection of the "explosive" warming associated with the breakdown of the wintertime polar vortex in the stratosphere.

Acknowledgment. We should like to thank Mr. Andrew W. McCulloch of the Goddard Space Flight Center, who carried out the radiometer experiment on TIROS VII, for kindly making available to us the initial radiation data discussed above.

REFERENCES

Bandeen, W. R., R. A. Hanel, John Licht, R. A. Stampfl and W. G. Stroud, 1961: Infrared and reflected solar radiation measurements from the TIROS II meteorological satellite. *J. geophys. Res.*, **66**, 3169–3185.

Hanel, R. A., W. R. Bandeen and B. J. Conrath, 1963: The infrared horizon of the planet Earth. *J. atmos. Sci.*, **20**, 73–86.

King, J. I. F., 1956: The radiative heat transfer of Planet Earth. *Scientific uses of earth satellites*, Ann Arbor, University of Michigan Press, 133 pp.